

Modeling Coastal Ocean Optical Properties for Coupled Circulation and Ecosystem Models

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Award Number: N0001497C0019

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LONG-TERM GOAL

The overall goal of this work is to develop an extremely fast radiative transfer model for use in coupled physical-biological-optical ecosystem models, and then to use those models for understanding the ocean optical environment.

OBJECTIVES

Currently available ecosystem models generally use fairly sophisticated treatments of the physics (e.g., mixed-layer thermodynamics and advection) and biology (e.g., primary production and grazing) but use grossly oversimplified treatments of the optics. The optics component of coupled models is often just a single equation parameterizing the scalar irradiance or photosynthetically available radiation (PAR) in terms of the chlorophyll concentration. Such simple models often fail even in Case 1 waters, and they can be wrong by orders of magnitude in Case 2 waters. The objective of this year's work was to develop a radiative transfer model that can be used in coupled models to bring the optics component up to the level of accuracy and sophistication needed for ecosystem models that are being applied to any water body, including Case 2 waters.

APPROACH

The HYDROLIGHT 4.0 radiative transfer model (<http://www.sequoiasci.com/hydrolight.html>; see also Mobley, 1998) provides an accurate solution of the radiative transfer equation (RTE) for any water body, given the absorption and scattering properties of the water body and boundary conditions such as incident sky radiance and bottom reflectance. Liu, Woods, and Mobley (1999) and Liu and Woods (1999) have shown that the use of Hydrolight in a coupled ecosystem model greatly improves the model's prediction of the North Atlantic spring bloom. Unfortunately, the standard version of Hydrolight requires too much computer time to make it suitable for use in ecosystem models where the light field must be computed at many grid points and at time intervals of less than one hour. However, ecosystem models require only the scalar irradiance as a function of depth and wavelength, which makes it possible to optimize the Hydrolight code to run extremely fast. I therefore tailored the Hydrolight code to run as fast as possible with the constraint that the computed PAR value at the

Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE 30 SEP 1999		2. REPORT TYPE		3. DATES COVERED 00-00-1999 to 00-00-1999	
4. TITLE AND SUBTITLE Modeling Coastal Ocean Optical properties for Coupled Circulation and Ecosystem Models				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Sequoia Scientific, Inc, Westpark Technology Center, 15317 NE 90th Street, Redmond, WA, 98052				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 4	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

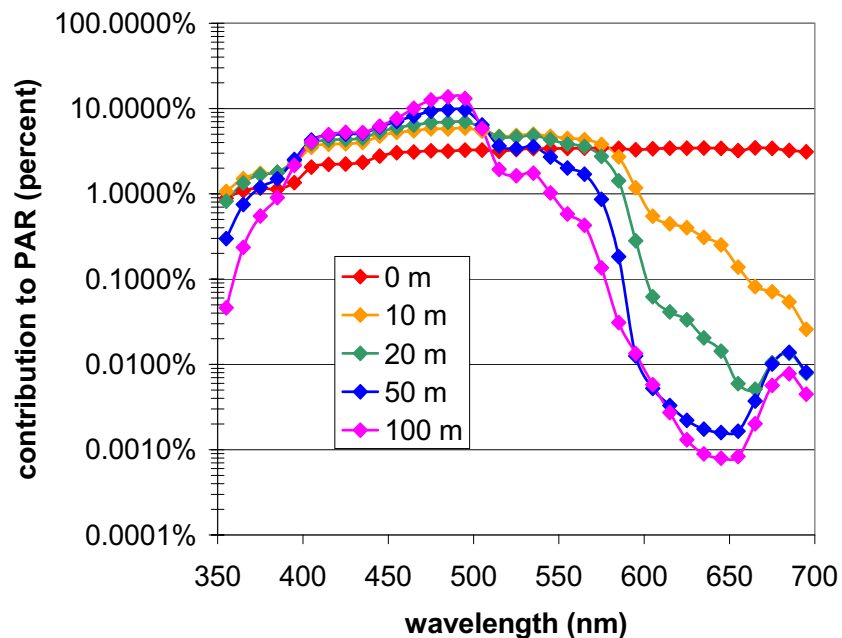
bottom of the euphotic zone must be accurate to ten percent.

This work was done in conjunction with Dr. Lydia Sundman of Sequoia Scientific and Dr. Ray Smith of the University of California at Santa Barbara, who is co-funded with me for analysis of the Plumes and Blooms data set (<http://www.ices.ucsb.edu/PnB/PnB.html>) taken in the Santa Barbara Channel.

WORK COMPLETED

This year's work started with an examination of the spectral scalar irradiance as a function of depth and wavelength for a variety of waters, including Case 1 waters with low to high chlorophyll concentrations and Case 2 waters with high concentrations of colored dissolved organic matter (CDOM) and mineral particles. The purpose of this study was to see what wavelengths contributed significantly to PAR as the water type changed.

Figure 1 shows an example of how much each wavelength contributes to PAR at various depths for a chlorophyll profile measured in the Atlantic Ocean in winter (Zelinski, et al., 1998, station ESTOC: *Chl* values were 0.2 to 0.3 mg m⁻³ down to ~100 m; the 1% PAR depth was ~120 m). In this instance, we see that it is necessary solve the RTE at wavelengths greater than 600 nm only to a depth of ~10 m, since those wavelengths do not penetrate well enough to make a significant contribution to PAR at deeper depths. Most of the contribution to PAR near the bottom of the euphotic zone (the 100 m curve) comes from wavelengths between 400 and 500 nm, so the RTE needs to be solved to great depths only for those wavelengths. The important wavelengths will of course be different for different water bodies, as will be the depths to which the RTE is solved.

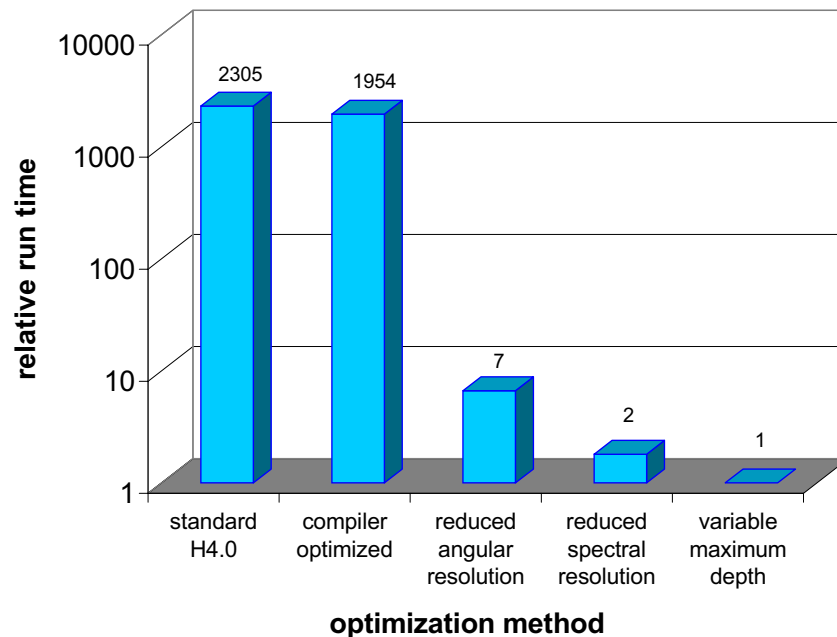


1. *Percent contribution of spectral scalar irradiance to PAR for a winter, Atlantic chlorophyll profile. An ordinate value of 1 at a given depth and wavelength, for example, means that 1 percent of the total PAR at that depth comes from that 10 nm wavelength band.*

Analyses such as that in Fig. 1 suggested several ways to optimize Hydrolight. Although it is still necessary to solve the radiative transfer equation to obtain the radiance distribution (from which the scalar irradiance is then computed), the radiance can be computed with less angular resolution, at fewer wavelengths, and to shallower depths and still obtain acceptably accurate scalar irradiances and PAR values. The primary changes allowing for an increase in speed were as follows:

- The code was compiled to run for speed.
- The angular resolution of the radiance distribution was reduced. In particular, only the azimuthally averaged radiance needs to be computed, since irradiances are obtained from azimuthal integrals of the radiance.
- The RTE is solved only for the wavelengths making a significant contribution to PAR.
- Inelastic scatter (fluorescence and Raman scatter) is omitted from the solution, which means that the RTE can be solved to different depths at different wavelengths.

Figure 2 show the increases in run time obtained from each of these changes, for the simulation used to generate Fig. 1.



2. Decrease in run times for various optimization steps. In this particular simulation, the fully optimized code ran 2305 times faster than the standard Hydrolight 4.0 code.

RESULTS

A special version of Hydrolight 4.0 has been developed for use in coupled ecosystem models. This version of the code runs up to several *thousand* times faster than the standard code, which makes it possible to compute the spectral scalar irradiance throughout the euphotic zone in less than one second

of time on a moderately fast personal computer. *There is no longer any excuse for using inaccurate optical submodels in coupled physical-biological-optical ecosystem models.*

IMPACT/APPLICATION

Predictive ecosystem models are playing an increasingly important role in our understanding of the oceans. Applications of such models range from predictions of water clarity for military purposes to management of coastal waters for fisheries. The incorporation of the optimized code developed here into coupled ecosystem models will give improved accuracy in the predictions of primary production and related quantities made by such models. As the coupled models become more trustworthy in their predictions, they will become even more valuable as tools for ocean science.

TRANSITIONS

Beta-test versions of the optimized Hydrolight 4.0 code have been delivered to Drs. Paul Bissett and Ray Smith, who will use the code in coupled ecosystem models for the Florida shelf and the Santa Barbara Channel, respectively. Their work is also part of the HyCODE program.

RELATED PROJECTS

This work is being done in conjunction with Dr. Oliver Zelinski of the University of Oldenburg, Germany, who is also interested in coupled ecosystem models. A joint publication on this year's results is in preparation.

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PUBLICATIONS

Liu, C-C, J. D Woods, and C. D. Mobley, 1999. Optical model for use in oceanic ecosystem models, *Applied Optics*, 38(21), 4475-4485 .